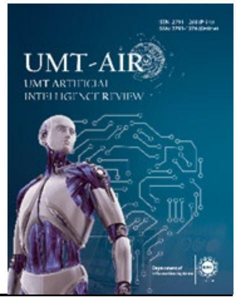
**UMT Artificial Intelligence Review (UMT-AIR)**
**Volume 2 Issue 2, Winter 2022**
ISSN(P): 2791-1276 ISSN(E): 2791-1268
Homepage: https://journals.umt.edu.pk/index.php/UMT-AIR

**Article QR**

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| **Title:** | **Analyzing the Application of SIR Model to Study the Outbreak of COVID-19: A Case Study in Pakistan** |
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| **DOI:** | https://doi.org/10.32350.umt-air.22.01 |
| **History:** | Received: October 10, 2022, Revised: November 16, 2022, Accepted: December 12, 2022 |
| **Citation:** | |
| **Copyright:** | © The Authors |
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| **Conflict of Interest:** | Author(s) declared no conflict of interest |

A publication of
Department of Information System, Dr. Hasan Murad School of Management

University of Management and Technology, Lahore, Pakistan

# Analyzing the Application of SIR Model to Study the Outbreak of COVID-19: A Case Study in Pakistan

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***Abstract-*** **The current study aims to examine the exponential rate of the spread of COVID-19 by employing a system dynamic model. The outbreak of COVID-19 was first evidenced on Feb 26, 2020 in Pakistan. The local bodies and law enforcing agencies took the initial preventive measures to restrict COVID-19 to a particular locality but all in vain. A large number of people were infected by this virus which increased the death rate countrywide. The numbers of infected people were alarming and a need was felt to develop the model to calculate the existing reproduction number and transmission rate and highlight its varied values in the coming days. People-friendly measures and government-based policies must be explored to fight against this deadly disease. This paper aims to develop an epidemic model using the system dynamic framework on simulation software STELLA. Additionally, the current study's purpose is to experiment with the system dynamic model to replicate the progression of the communicable disease and probe multiple combinations of people-based and government-based measures to reduce the spread of COVID-19 pandemic. These containment measures are of two types; people-based measures and government-based measures which directly affect the reproduction number and infection growth rate of the mitigating circumstances due to COVID-19. Combined efforts of the public and government can combat this global pandemic. The reduced number of reproduction number/recurring cases and infection growth rate are the key metrics to judge and evaluate the effectiveness of containment/ control measures. Therefore, this research points to a more holistic combination of public and government-oriented measures that play a vital role in reducing the increasing infection rate of COVID-19. Simulation results were traced to replicate the real-life settings against four combinations of containment**

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**measures in tabular form and graphical form.**

***Index Terms-*** **COVID-19, containment measures, epidemic model, Pakistan, system dynamics**

## I. Introduction

COVID-19 is an emerging biohazard which has drastically impacted millions of people globally, causing many deaths with its exponential transmission rate.

In current study, a system dynamic model has been devised [1] to implement a well-known (Susceptible-Infected-Recovered) SIR model [2] which is an epidemiological model that consists of three coupled non-linear equations [3] that represent the real-life setting and grounded in the data gathered from the secondary source for instance, a government website. In this research, the system dynamics model is developed in computer-based simulation software STELLA professional version 1.1.2 using the system dynamics modelling framework [4]. Simulated SIR model replicates the real-life data gathered over the period of 55 days and experimentation with the model helped to explore the possibilities of containment measures which would help to reduce the increased infection rate. It also predicts that to draw a comparison between people vs government-based measures.

The outbreak of COVID-19 was reported in the end of December in 2019 in Wuhan, China. It is a highly contagious disease with an expeditious transmission rate and because of this, the WHO has announced a Public Health Emergency of International Concern on 31st January 2020 [5]. On the account of its accelerated global spread, it was declared a pandemic, by World Health Organization on 11th March 2020, due to thirteen-fold increase in cases in two weeks. The basic recurring cases of COVID-19were estimated around 2.2 (range 1.4-6.5) [5]. In Pakistan the very first case of COVID-19 was reported on 26th February, 2020 owing to its geographical association with China and Iran with continuous immigration of people [6]. Unluckily, the first immigrant was from Iran in Sind province. In order to combat COVID-19, preventive measures were enforced by the provincial government and unprecedented measures were taken to control the pandemic. Till March 26, 2020, 1197 cases of COVID-19 were reported with 9 deaths. Significantly, an immediate lockdown was imposed on March 2020, and it was gradually eased till 9th May, 2020 to shore up the

economy. Over the period of 55 days till April 20, 2020 the total number of infected cases in Pakistan reached to 8418 with 1970 recoveries and 176 deaths.

Pakistan is currently fighting two battles; one against corona virus/COVID-19 and the other one against poverty. This economic meltdown is due to the disruption of supply chains, lockdown, and sudden closure of businesses leading to decreased livelihood opportunities (Narmeen et al., 2022). Additionally, a huge amount of money was consumed for the implication of safety measures, PPEs, testing kits, and increasing health care facilities. Favero, et al. [7] have categorized the effectiveness of strategic policies for COVID-19 on the basis of their costs and fatalities in their research article “Restarting the economy while saying lives under COVID-19’’ on 8th May, 2020 to optimize the management strategies from the ecological viewpoint.

In another research article ‘‘ Why is it difficult to accurately predict the COVID-19 epidemic’’ Roda et al. [8] have mentioned that detected cases are only a fraction of total infected people using the metaphor of an iceberg since many asymptomatic patients are not even tested making it difficult to predict the disease course. In this research study, Roda and others emphasized the significance of SIR model which is better in predicting the disease progression than SEIR and other complex models. SIR model provides a clear theoretical verification of the effectiveness of the mitigating strategies. This strict implication of this model can halt the epidemic surge and it can be used to address the risk of second peak if occupational S activities are started during the disease course.

The objective of the current research is to understand the containment measures, their need, and significance to push down the infection rate of COVID-19.

## II. Research Methodology

System dynamic model is a versatile methodology/ framework which deals with the non-linear, dynamic, and complex problems [9] in industrial, social, and medical sciences. System dynamic masterly attempts to combine the key concepts like feedback controls, mutual causality, non-linearity in the functions, cybernetics, complexity, counterintuitive behaviour, deviation correcting, and deviation amplifying processes to the organizational systems [10].

COVID-19 has enhanced the importance of disease

epidemiological modelling. A well-known epidemiological model SIR (Susceptible, infected, and resolved) is a recent development [2]. Even the common man is interested to know about the infection rate and resolution rate. There is a need to develop the SIR model using system dynamics modelling framework to determine the containment measures to control the governing factors BETA (Infection rate) and GAMMA (Resolution rate) which is a reason for the wide spread this disease.

### *A. Research Questions*

1. Is the SIR model using the system dynamics modelling framework truly represent the viral growth of the COVID-19 in Pakistan?
2. Which of the containment measures are more effective in COVID-19(government-oriented or people-oriented)?

### *B. Model Structure*

Figure 1.indicates the simplified representation of the SIR epidemic model. Saturation loop **(S)**, reinforcing loop **(R)**, and balancing loops **(B)** exist in the model to generate the model behaviour. The loop dominance may change over the period of time and creates various modes of behaviour as the time passes. As the transmission rate increases due to the increase in the infected people, there is a decline in the susceptible people (people who are healthy but are at risk) and it is going to saturate till all the susceptible persons become infected. Model structure represents the stock and flow diagram and the symbols used in this model are shown in Appendix A.

The value of the gamma recovery rate give strength to the balancing loop. No doubt the constant value of gamma does not bring significance effect of the resolved people. Changing values of the BETA (infection rate ) keep on increasing the stock of infected people and susceptible people becomes the infected at exponential rate, if there is no vaccine for susceptible [11]. The spread of COVID-19 is with a jet speed. Limited testing and screening facilities, non-availability of the testing kits, poor quality of kits, and low quality personal protective equipment which are the hurdles to catch the viral growth ofCOVID-19

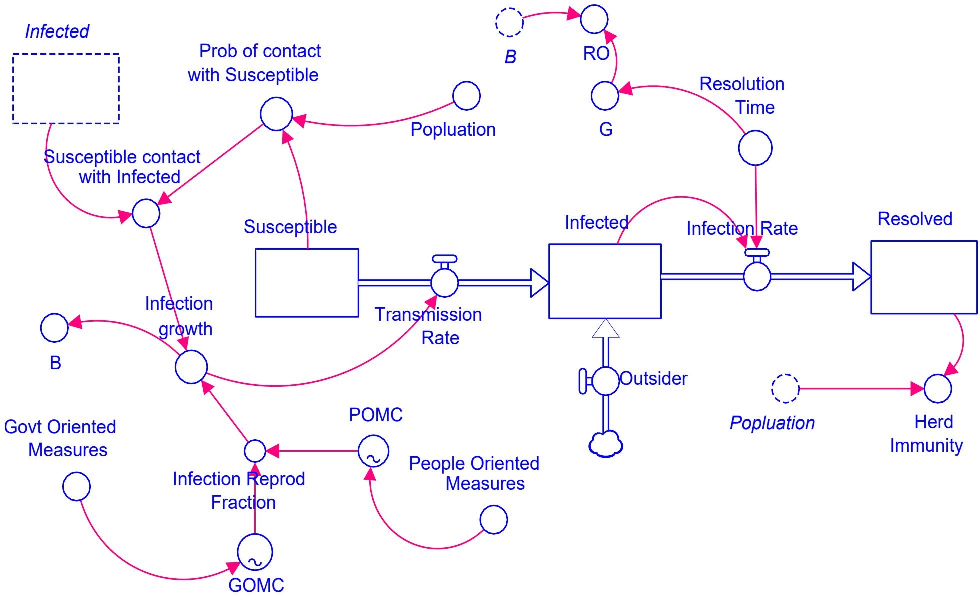


**Fig. 1.** Stock and flow diagram of SIR epidemic model

Table I
Anatomy of SIR Model

| Symbol | Nomenclature | Description |
|---|---|---|
| S | Susceptible | How many available for infection |
| I | Infected | How many are infected |
| R | Resolved | How many are resolved either recovered or died (no longer part of total population) |
| B | Beta | Number of contacts per infected person per day |
| G | Gamma | Number of recoveries per person per day |
| R0 | Reproduction Number | Reproduction number is used to measure the transmission potential of a disease. It is the average number of secondary infections produced by a typical case of an infection in a population where everyone is susceptible. |
| N | N | Total Population i.e N=S+I+R |

The model consists of three non-linear differential equations based on Euler method where 't' is the time, Beta is the infection rate, and gamma are the resolution rate.

$$dS/dt = -Beta * S * I \tag{1}$$

$$dI/dt = Beta * S * I - Gamma * I \tag{2}$$

$$dR/dt = Gamma * I \tag{3}$$

$$N = S + I + R \tag{4}$$

Beta is the infection rate that is a controlling variable that transmission from susceptible to infected and ratio of Beta to Gamma is called reproduction number (RO), which determine the spread of COVID-19 pandemic [12]. It is interesting to note that infection rate (Beta) and reproduction number (RO) both exponentially raised together. The model is calibrated fifty-five (55) days for the value of infection rate (Beta) and resolution rate (gamma) as shown in the Figure 2 and Figure 3.

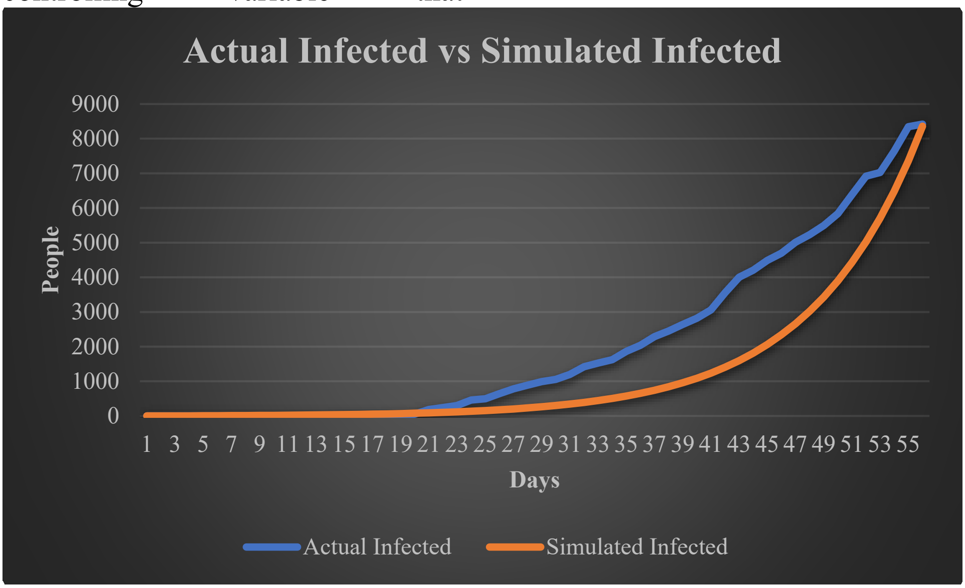


**Fig. 2.** Actual infected vs simulated infected

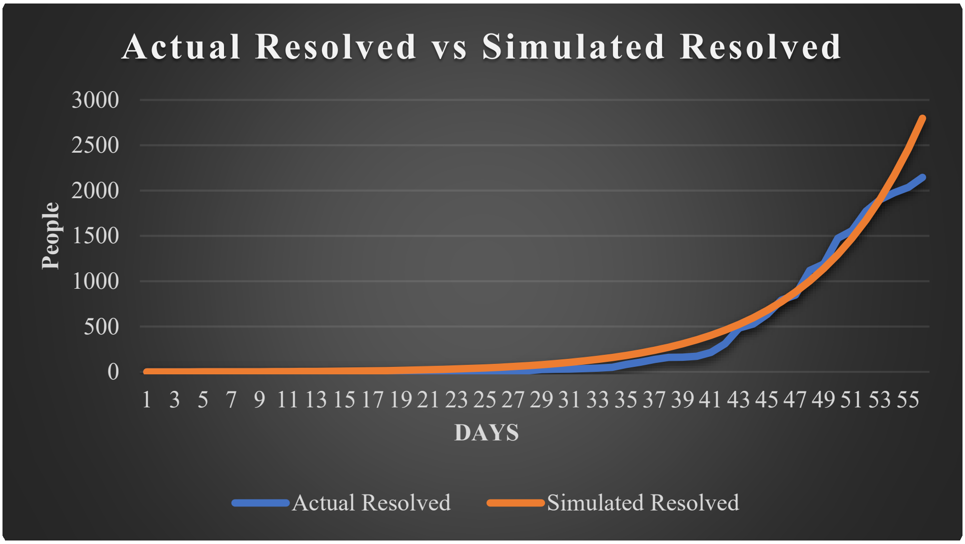


**Fig. 3.** Actual resolved vs simulated resolved

The days to resolve either recovered or died usually it takes around 23 days. The model is the third order differential equation with associated flows [13]. The order of the model depends upon the number of levels and the number of delays [14]. The details of the model variables are highlighted in Appendix B.

### 2.3 Base Line Model Equations

SIR model based on Euler integration are as under:

Susceptible = INTEGRAL (-Transmission rate) * dt (1)

Transmission rate = Infection growth (1.1)

Infection growth = Infection reproduction fraction * susceptible contract with infected (1.2)

Susceptible contact with infected = probe of contact with susceptible * infected contact (1.3)

Infected contact = Contact rate * Infected (1.4)

Probe of contact with susceptible = Susceptible / population (1.5)

B = Infection growth (Beta represents infection rate) (1.6)

Infected = INTEGRAL (Transmission rate – infection rate + outsider inflow) * dt (2)

Infection rate = Infected / Resolution time (2.1)

Outsider Inflow = One person per day (Constant) (2.2)

Resolved = INTEGRAL (Infection rate) * dt (3)

Herd Immunity = Resolved / Population (3.1)

G = 1/resolution time (Gamma represents the resolution rate) (3.2)

RO= B/G (3.3)

## 2.4 Model Assumptions

The summation of all the stocks and rates are equal to the total population that depicts the dynamic balance [15]. The system dynamic model has following assumptions:

1) There is a fixed recovery time in COVID-19
2) People are well mixed and cannot segregate the asymptomatic with people with healthy people
3) There is no information about the immunity loss period
4) Infected person would not get infected again

## 2.5 Model Behaviour

On the basis of the actual time series data, the system dynamics model was calibrated for fifty-five days and the data is highlighted in Figure 2 and Figure 3, representing the true picture of COVID-19 and its spread in Pakistan. Considering the people-oriented measures and government-based measures it was observed that model behaviour is an essential measure for the containment of COVID-19. A detail of model equations has been shown in Appendix C. The value of Beta (infection rate ) and Gamma (resolution rate) was derived from the time series data of Pakistan and world statistics on COVID-19 [16] to trace of the behavioural patterns of various simulation periods for the validated estimations. The various containment measures as shown in the Table 2 have been proposed for experimentation. The only fifty-five days had passed so far and level of awareness was minimal. If we project the model behaviour for next 365 days the results are shown in Figure 4 which indicate the peak would appear after 146 days and by that time 80 million people would be infected and around 120 million people would be resolved. These figures were so alarming that compelled the researcher to investigate and explore the effectiveness of the containment measures to reduce the infection rate. The model consists of positive and negative loops [17] and dominance of the polarity and its shift from positive to negative and negative to positive adds complexity [18]

Table II
Containment Measures People based Versus Government based

| People-Based Measures | Government-Based Measures |
|---|---|
| Hand washing | Lock down duration |
| Social distancing | Lock down effectiveness |
| Avoid meetings, get-togethers, parties, festivals | Contact trancing and quarantine people on quarantine centers |
| Self-isolation and quarantine | Smart Lock Down-Open up with Standard Operating Procedures (SOPs) like temperature gun, PPEs, Face mask, and frequent medical checkup |
| Maintaining the 6 feet distance between two individuals | Usage of facemasks  are mandatory for visiting the shops and all public places |
| Using the hand sanitizers | Walk through Dis-infected tunnels for company employees and entrants in shopping malls, hospitals, factories, airports, and retail outlets |

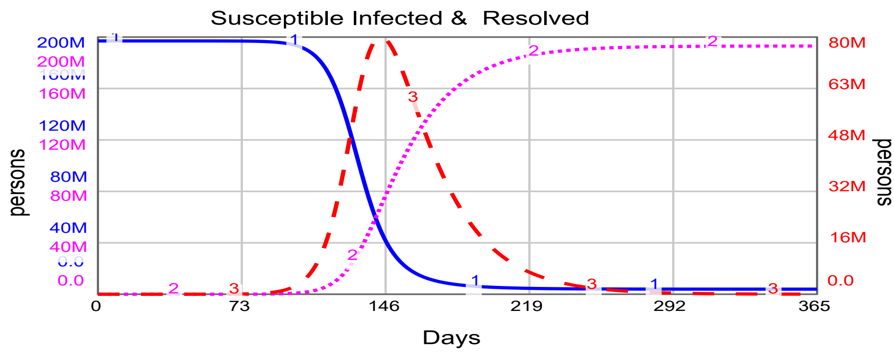


**Fig. 4.** Susceptibles, infected, and resolved during the simulation period 365 days

Graphical functions based on people oriented measures and government oriented measures have been introduced in the Appendix D, and was designed to understand the behavioural patterns arising from

the model structure rather than point prediction of the future deaths and recoveries [15]

## III. Results and Discussion

People based measures like social distancing is a non-pharmaceutical prevention containment measure that is the outcome of people behaviour and their attitude [19]. Knowledge, understanding, and attitude of medical students [20] contributed productively to run the awareness campaigns about wearing face mask, proper hand-wash , strict usage of sanitizers, maintaining social distance, avoid parties, social get together, festivals, and funerals. All the above mentioned actives highly rely on people attitude and their behaviours, and are often associated with people-friendly measures. However, government based measures are associated with lock down duration, lock down effectiveness, contract tracing, enhancing health care capacity, smart lock down with the effective implementation of standard operating procedures (SOPs), and personal protective equipment (PPEs). Lock down duration during day time stopped everything and other government-oriented initiatives are very much impeded in it as highlighted in Table II.

The model was calibrated for initial 55 days and then under the government-based measures and people-based measures the actual data was replicated till July 10, 2020 with the simulation numbers indicating the reduced reproduction number. The details are shown in Table 3 given below.

The effectiveness of the containments of people-based and government-based preventive measures are equally important and significant to reduce the reproduction number shown in Figure 7. This number lead to the lowered infected rate among people as highlighted in Figure 5 due to reduced level of beta-infection fraction as shown in Figure 8. This diversity in patterns of behaviour is under the influence of multiple combinations of people based and government based containment measures [21]. Measure reference indicates the set of combination (people-based and government-based) of containment measures. The number 1 measure represents the base value and that was the source of model calibration after passing fifty-five (55) days. Reproduction number has gone down from 3.97-2.68 that shows the government effective strategy, which is at the right track as shown in Table III

Table III
Lowering Reproduction Number Shows Effectiveness of the Containment Measures

| Period | Days | Actual Infected | Simulated Infected | Actual Resolved | Simulated Resolved | Reproduction Number | Measures Reference | People Based Measures (%) | Government Based Measures Days |
|---|---|---|---|---|---|---|---|---|---|
| Ist Period | 55 | 8418 | 8400 | 2146 | 2800 | 3.97 | Base Case No. 1 | 15 | 30 |
| 2nd Period | 85 | 45898 | 44000 | 14086 | 19000 | 3.29 | Measure No 2 | 17 | 55 |
| 3rd Period | 116 | 171666 | 171000 | 66886 | 89000 | 2.92 | Measure No. 3 | 21.5 | 62 |
| 4rth Period | 136 | 243599 | 255000 | 154151 | 152000 | 2.68 | Measure No. 4 | 24.5 | 65 |

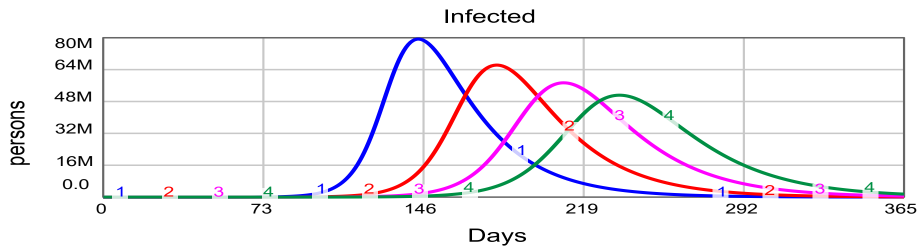


**Fig. 5.** Affect of containment measures on infected people at varied time intervals

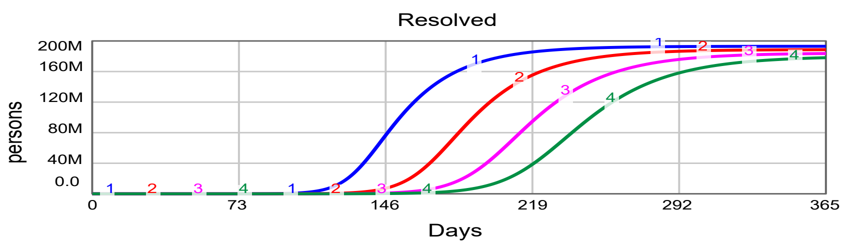


**Fig. 6.** Affect of containment measures on resolved people at varied time intervals

Number of recurring COVID-19 cases have gone down due to the decrease in infected people as highlighted in Figure 6. Beta-infection fraction has declined from 0.18-0.11 as shown in Figure 8. This is the average result of people's attitude and fear aroused due to the increased deaths reported on daily basis.

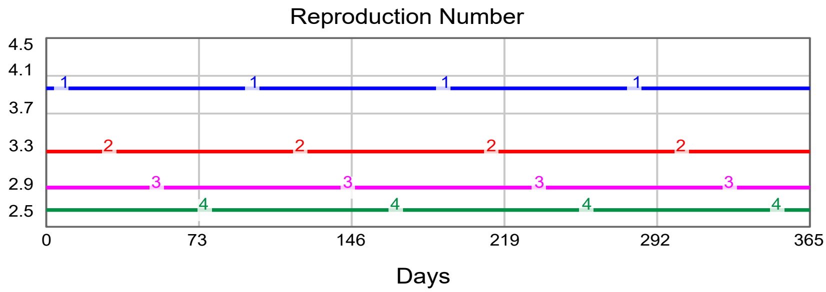


**Fig. 7.** Affect of  containment measures on reproducton numbers at varied time intervals

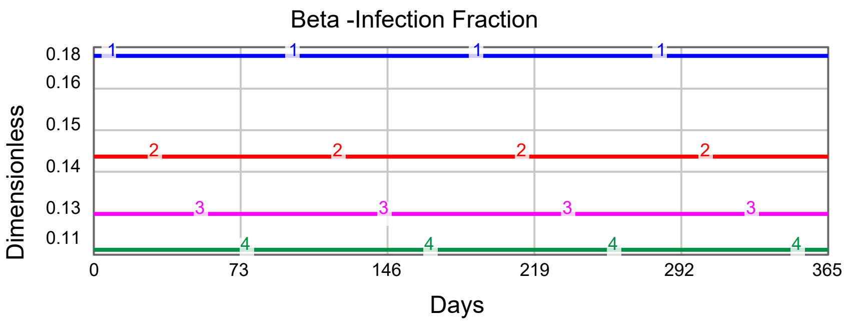


**Fig. 8.** Affect of  containment measures on beta-infection fraction at varied time intervals

## IV Conclusion

System dynamics model is used to be explored and experimented with various combinations of containment measures [22] and determining the various levels of reproduction number and beta-infection fraction to mitigate the spread of infectious disease COVID-19. The current study concluded that system dynamic model was effectual in preventing COVID-19 and its outbreak. Thereby, the government-oriented measures were more effective than people-oriented measures. People oriented measures are primarily, based on education, effectiveness of the awareness campaigns, attitude, and the mind-set of the social fabric. While measures based on attitude are mostly time dependent and cannot be achieved quickly. However, government has the power to establish and implement the policies using stick or carrot approach for the proper implementation of control measures. The immediate lockdown not only controlled the increasing infection rate but also restricted the spread of COVID-19 pandemic. This was made possible only by arranging emergency medical caps and health care centers to reduce the increased death rate. Hence, the effective contact tracing and lock down can contribute in the reduction of beta-infection fraction which helped in opening industries with SOPs during the pandemic.

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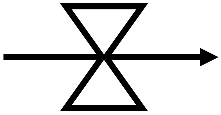
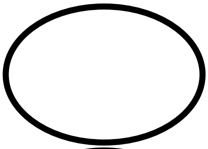
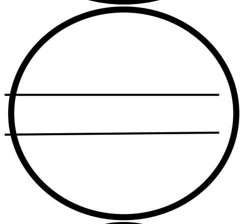
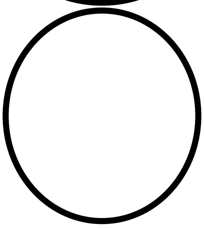
## Appendix A

Symbols for Flow /Block Diagram

| Description | Symbol | Associated Equation Type | Explanation |
|---|---|---|---|
| Level |  | L | Stock |
| Rate |  | R | Flow |
| Auxiliary |  | A | Convertor |
| Table Function |  | T | Perception map between x,y plane |
| Exogenous variable |  | E | Occasionally affect the model behavior but not part of model |
| Constant |  | C | Constant which has unique value |
| Source or Sink of Material |  | Define | Out of boundary, defines the model scope |
| Material / Information Flow |  | | Use for the movement of material and information |

# Appendix B

List of Variables

| Variables | Description | UOM | Equation Type | Parametric Value |
|---|---|---|---|---|
| Susceptible | Soft Skills Training conduction time | Persons | L | |
| Infected | Infected | Persons | L | 0 |
| Resolved | Resolved | Persons | L | 0 |
| Population | Population | Persons | C | 197000000 |
| Outsider | Outsider | Person | C | 1 |
| Resolution Time | Resolution Time | Days | C | 23 |
| Herd Community | Herd Community | Dimensionless | A | |
| Reproduction Number | Reproduction Number | Dimensionless | A | |
| Infection Rate | Infection Rate | Persons/Days | R | |
| Transmission Rate | Transmission Rate from Susceptible to infected | Persons/Days | R | |
| POMC | People Oriented Measures Correction | | T | |
| GOMC | Government Oriented Measures Correction | | T | |
| GOM | Government Oriented Measures | Days | C | 65 |
| POM | People Oriented Measures | Dimensionless | C | 0.245 |
| B | Infection Growth-Beta | Number of contacts per infected person per day | A | |
| G | Gamma-Reciprocal to Resolution Time | Number of recoveries per person per day | A | |
| Prob of Contacts with Susceptible | Probability of Contacts with Susceptible | Dimensionless | A | |

| Variables | Description | UOM | Equation Type | Parametric Value |
|---|---|---|---|---|
| Infected Reproduction Fraction | Infected Reproduction Fraction | Dimensionless | A | |
| Susceptible Contact with infected | Susceptible Contact with infected | Persons | A | |
| Infection Growth | Infection Growth | Persons per day | A | |

## Appendix C

Programming for System Dynamics Simulation Model on STELLA Professional Software Version 1.1.2

### SIR Model Equations

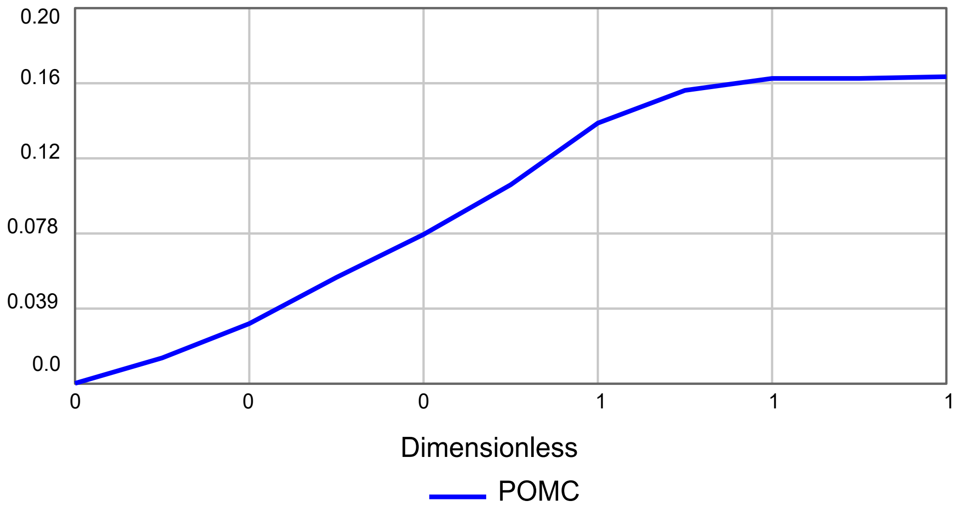
Top-Level Model:
Infected(t) = Infected(t - dt) + (Transmission_Rate + Outsider - Infection_Rate) * dt
INIT Infected = 0
UNITS: persons
INFLOWS:
Transmission_Rate = Infection_growth
UNITS: persons/days
Outsider = 1
UNITS: persons/days
OUTFLOWS:
Infection_Rate = Infected/Resolution_Time
UNITS: persons/days
Resolved(t) = Resolved(t - dt) + (Infection_Rate) * dt
INIT Resolved = 0
UNITS: persons
INFLOWS:
Infection_Rate = Infected/Resolution_Time
UNITS: persons/days
Susceptible(t) = Susceptible(t - dt) + ( - Transmission_Rate) * dt
INIT Susceptible = Popluation-Infected
UNITS: persons
OUTFLOWS:

Transmission_Rate = Infection_growth
UNITS: persons/days
B = Infection_growth
G = 1/Resolution_Time
GOMC = GRAPH(Govt_Oriented_Measures)
(0.0, 0.0000), (36.5, 0.0460), (73.0, 0.0799), (109.5, 0.1073), (146.0, 0.1290), (182.5, 0.1404), (219.0, 0.1518), (255.5, 0.1598), (292.0, 0.1655), (328.5, 0.1735), (365.0, 0.1769)
UNITS: persons per days
Govt_Oriented_Measures = 65
UNITS: Days
Herd_Immunity = Resolved/Popluation*100
Infection_growth = Susceptible_contact_with_Infected*Infection_Reprod_Fraction
UNITS: persons/days
Infection_Reprod_Fraction = 0.234-POMC-GOMC
UNITS: Dimensionless
People_Oriented_Measures = 0.245
UNITS: Dimensionless
POMC = GRAPH(People_Oriented_Measures)
(0.0000, 0.000205), (0.0950, 0.0134), (0.1900, 0.0312), (0.2850, 0.0552), (0.3800, 0.0775), (0.4750, 0.1033), (0.5700, 0.1353), (0.6650, 0.1523), (0.7600, 0.1585), (0.8550, 0.1585), (0.9500, 0.1594)
UNITS: Dimensionless
Popluation = 197000000
UNITS: persons
Prob_of_contact_with_Susceptible = Susceptible/Popluation
UNITS: Dimensionless
Reproduction_Number = Infection_Reprod_Fraction/G
Resolution_Time = 23
UNITS: Days
Susceptible_contact_with_Infected = Infected*Prob_of_contact_with_Susceptible
UNITS: person
{ The model has 20 (20) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 3 (3) Flows: 3 (3) Converters: 14 (14)
Constants: 5 (5) Equations: 12 (12) Graphicals: 2 (2)}

# Appendix D

Graphical Functions

Affect of People Oriented Measures on Infection Reproduction




Affect of Govt. Oriented Measures on Infection Reproduction